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# A HIGH-GAIN AND HIGH-EFFICIENCY SINGLE-LAYER SLOTTED WAVEGUIDE ARRAYS IN MILLIMETER-WAVE BAND

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## Introduction

There are strong demands for high gain and mass produceable planar arrays in millimeter wave. These include high speed wireless LAN, automotive collision avoidance radar and various types of millimeter-wave subscriber radio systems such as entrance radio link between base stations in mobile communications etc. They are summarized in Fig. 1. Higher efficiency antennas always contribute to the enhancement of the quality of the systems, in view of not only performance but also the system cost. In addition, most of these applications need high gain antennas of more than 25 dB. However the planar arrays reported in the literature adopt the microstrip or triplate lines as the feeder, which inherently suffer from serious loss in millimeter-wave band [1]-[3]. So, their efficiency would not exceed non-planar antennas such as lens and the reflectors. Figure 2 shows the efficiency of various types of planar arrays as functions of the gain and the frequency. They are decreasing as the gain and/or frequency become higher. It is roughly estimated that the efficiency of microstrip or triplate line arrays with 35 dBi would be lower than 30 % in 60 GHz for example. Waveguide slot arrays are the only and the most attractive candidates of high gain planar antennas in terms of efficiency, since the loss is the smallest amongst all the planar feeding structures. However, the complicated three-dimensional feed structure have been preventing the use for commercial application. Drastic reduction of manufacturing cost to the level of microstrip and triplate ones is necessary.

Authors have developed two types of unique waveguide slotted arrays. Radial line slot antennas ( RLSA ) is an oversized waveguide arrays, which are now commercially used and have remarkable efficiency of more than 85 % in 12 GHz band [4] [5]. A single-layer planar array using the dominant mode waveguides has the efficiency of more than 75 % and the gain of 26 dBi in 12 GHz band [6]. They have been the highest efficiency antennas in these frequency ranges. In principle, these antennas are high efficiency even in higher gain and higher frequency since the feeding loss is negligibly small. This paper extends the design of a single-layer dominant mode waveguide arrays in millimeter-wave frequency and demonstrates the excellent performance.

## Planar waveguide array with a single layer $\pi$-junctions [7]

Figure 3 shows the structure of the single-layer slotted waveguide array. A plate with etched slots and a grooved structure are the two components in this antenna; diecasting technique may be applied for the latter and this antenna has high potential in mass-produceability. Two-dimensional arrays in 22 GHz and 60 GHz bands are manufactured for experiments. High accuracy is required in manufacturing the antennas in such a high frequency band. Design parameters are listed in Table 1. Especially in 60 GHz band, the size of the antenna is small even it is a high gain one. It has the size of about 105 mm × 120 mm × 5 mm, 600 resonant shunt slots on 24 waveguides of 3.22 mm × 1.88 mm. The typical size of slot is 3 mm × 0.3 mm. The wall thickness between the waveguides is 1 mm. One feed waveguide is two series of six $\pi$-junctions, each one of which excite two radiating waveguides via one window; 12 windows with numerically designed width excite 24 waveguides in equal amplitude and phase. The electromagnetic analysis of $\pi$-junctions is 2 dimensional and highly reliable. Slots are designed for uniform illumination by Galerkin's method of moments [8]. Mutual coupling effects are simulated by using periodic boundary conditions [9] and the slot design can be conducted by a personal computer.

## Experiments

Figure 4 shows gains of 22 GHz band antenna. Excellent characteristics are obtained and the peak gain is 35.9 dB ( antenna efficiency: 76 % ) which is much higher than those of any other types of planar arrays in this frequency and gain range. Figure 6 presents the gain of the 60 GHz band antenna as well as the predicted one. The highest gain of 35 dBi and the efficiency of 59 % is observed at 60.2 GHz. This efficiency is quite high and is about two times larger than that predicted for other types of antennas. These results are also included in Fig. 2. We have already confirmed by experiments that the gain degradation in lower frequency is due to the return loss in Fig. 5, which can be improved by chosing larger beam tilting angle.

## Alternative structures

For further enhancement of efficiency and reduction of cost, TEM waveguide ( radial line ) and alternating phase waveguide using T-junctions are attractive, since these dispense with the vertical walls or its electric contact, respectively. They will also be reviewed.

## Conclusion and further studies

A single-layer waveguide array is designed at 22 GHz and 60 GHz band. Excellent efficiency of more than 75 % ( gain: 35.9 dBi ) and 55 % ( gain: 35.1 dBi ) were measured, respectively. For realizing the ideal efficiency of 90 % in principle, the critical point in the fabrication of this antenna would be the bonding between two elements, that is a slotted plate and a grooved feeding structure. Accurate alignment and perfect electrical contact is required. Low cost and mass produceable technique should be established.

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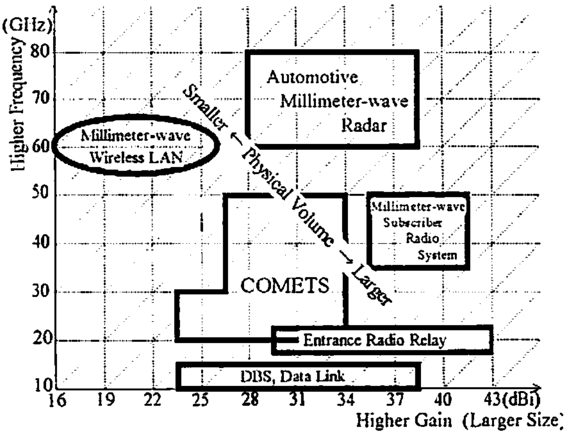


Fig. 1 Application in high-frequency and high-gain range

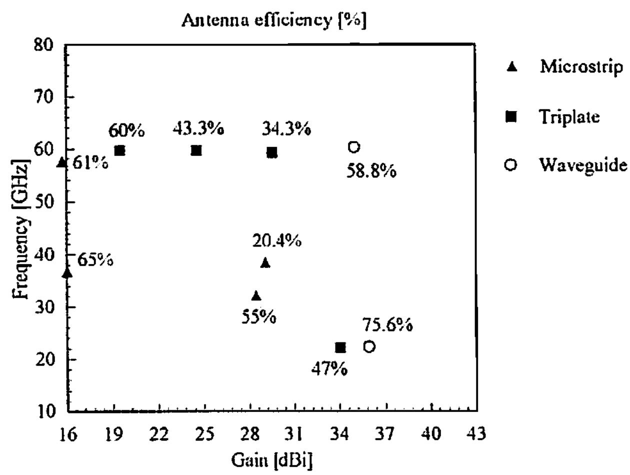


Fig. 2 Antenna efficiency of various types of planar antennas

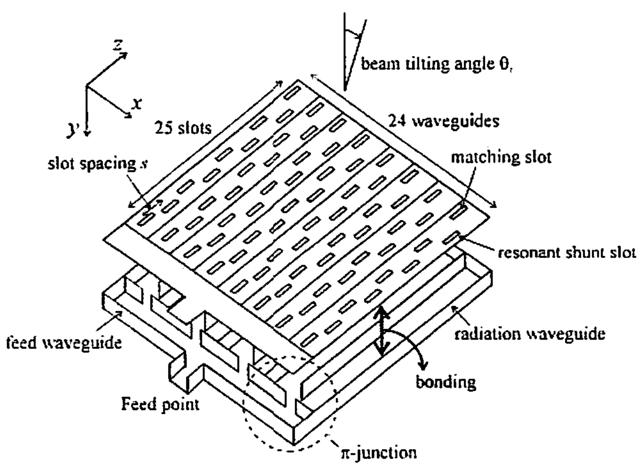


Fig. 3 Structure of single-layer waveguide array

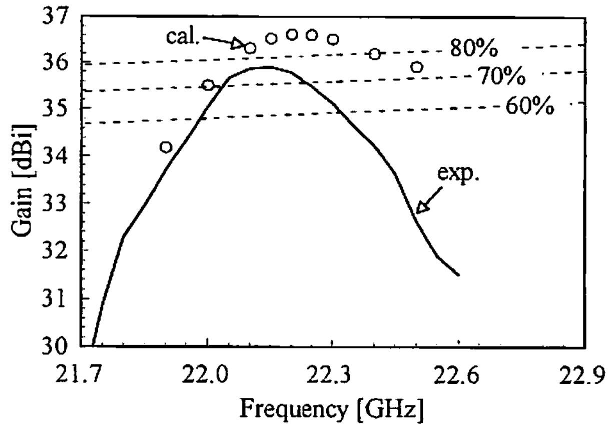


Fig. 4 Gain and antenna efficiency of 22 GHz band antenna

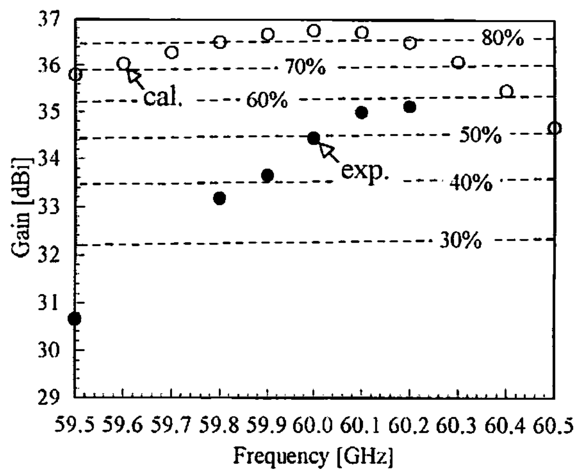


Fig. 5 Gain and antenna efficiency of 60 GHz band antenna

Table 1 Design parameters

| Design frequency | 22.2 GHz | 60.0 GHz |
|---|---|---|
| Number of radiating waveguides | 24 | 24 |
| Number of slots ( one waveguide ) | 25 | 25 |
| Number of slots ( all ) | 600 | 600 |
| Array length ( $z$ ) | 260 mm | 120 mm |
| Array length ( $x$ ) | 280 mm | 105 mm |
| Broad guide width of feed waveguide $a_f$ | 8.1 mm | 3.10 mm |
| Broad guide width of radiating waveguide $a_g$ | 10.0 mm | 3.22 mm |
| Narrow guide width $b$ | 4.0 mm | 1.88 mm |
| Wall thickness between waveguides | 2 mm | 1 mm |
| Slot plate thickness | 0.5 mm | 0.2 mm |
| Typical slot length | 6.5 mm | 2.3 mm |
| Slot width | 1 mm | 0.3 mm |
| Slot spacing $s$ ( $z$ ) | 10.6 mm | 4.30 mm |
| Beam-tilt angle | 6 deg | 2.4 deg |